

Short- and long-term tillage effects on *Heterodera glycines* reproduction in soybean monoculture in west Tennessee[☆]

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ABSTRACT

Soybean cyst nematode, *Heterodera glycines* has been documented as the pathogen most consistently causing yield loss in US soybean production fields almost since its discovery in the US. No-tillage has been adopted in much of the soybean production areas to preserve soil and nutrients. The impact of this production practice change on soybean cyst nematode has been evaluated since the introduction of the practice over thirty years ago and mixed results on the impact have been recorded. This study was initiated to determine if tillage practices and timing of changes impacted soybean cyst nematode reproduction. The study was imposed on a long-term tillage study and treatments were changed to measure short-term as well as long-term effects of tillage on soybean cyst nematode. Significant differences in soybean cyst nematode population density were found between treatments. However, significant differences found could be attributed to short-term changes in tilled and no-tilled treatments. Soybean cyst nematode reproduction was almost twice as high in treatments which changed from no-tillage to disc than tilled treatments changed to no-tillage. No significant differences were found in yield among the treatments. Grain yield was reflective of cultivar grown and environmental conditions.

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1. Introduction

Soybean cyst nematode (SCN), *Heterodera glycines*, Ichinohe, has been documented as the pathogen most consistently causing yield loss in US soybean production fields (Wrather and Koenning, 2006). Crop production practices have a direct or indirect effect on plant root function, and therefore the impact of tillage on root pathogenic nematodes has been of interest (Caveness, 1974; Thomas, 1978; Southards, 1971) and continues of interest. Crop rotation and use of plant resistance have long been used as methods to reduce SCN; however, these strategies reduce the risk of yield loss but do not eliminate the risk. Management strategies such as row spacing, date of planting, tillage regimes, and trap crops are some of the strategies that have been explored as additional ways to reduce the impact of SCN. Management strategies such as no-tillage, which have increased yield and reduced soil and nutrient runoff, have been explored most extensively to determine the impact on management of SCN.

The effects of tillage practices on *H. glycines* reproduction have been mixed. Koenning et al. (1995), Tyler et al. (1983, 1987), Baird and Bernard (1984), and Workneh et al. (1999) all found that no-tillage decreased the population density of SCN. Chen et al. (2001), Noel and Wax (2003), and Hershman and Bachi (1995) found no effect of tillage systems on SCN population density. Several explanations have been proposed for the conflicting results. Studies such as Tyler et al. (1987) suggest that results of SCN population density are temporal in relation to the initiation of no-tillage. The above studies were direct comparisons between sites with mixed tillage histories and not systems where comparisons were made between recent changes and long-term systems.

There have been various theories concerning the abiotic and biotic effects of no-tillage on SCN reproduction. Abiotic effects include lower soil temperature, additional soil water, increased soil organic matter, changes in soil bulk density, pore size, and water infiltration rate (Bernard et al., 1996). It is well known that soil temperature is temporally lower in no-till partially due to the presence of residue (Griffith et al., 1975), and temperature is a major driving force on the length of the SCN life cycle (Ross, 1964). Optimal temperatures for SCN life stage development have been documented (Alston and Schmitt, 1988), and lower soil temperature would lengthen the life cycle and potentially reduce the number of eggs in the soil reservoir during the growing season by reducing the number of SCN generations. Soil water is interrelated

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to soil temperature. Debris on the soil surface from no-tillage conserves water near the soil surface (Tyler and Overton, 1982; Blevins et al., 1971). Heatherly et al. (1982) found SCN developed best near 0.03 MPa in the top 0.15 m of the soil profile. Johnson et al. (1993, 1994) found little direct relationship between agronomic characters and their relationship to water potential or SCN infestation level. Heatherly et al. (1992), Heatherly and Young (1991) and Young and Heatherly (1988) investigated effects of water potentials on SCN reproduction in greenhouse, microplot and field experiments and found that irrigation could not negate the stress from SCN in a susceptible cultivar. However, soil moisture may influence the establishment and location of the SCN juvenile feeding site (Endo, 1964). Increased soil water, lower soil temperatures, and non-incorporation of residue under no-tillage may result in increased organic matter as compared to soil environmental conditions with tillage (Aina, 1979; Tyler et al., 1983). Widmer et al. (2002) in a review of the effects of soil organic matter found a negative correlation between plant parasitic nematodes and increasing soil organic matter. Organic matter can increase fungal parasites of SCN (Ginitis et al., 1982, 1983). No-tillage is reported favoring an increase in facultative anaerobes (Doran, 1980). Caesar-TonThat et al. (2007) found that tillage influences soil bacteria which contribute to soil aggregates. Microaggregates stabilize soil and are thought to provide habitat for soil organisms which lead to increased soil quality. They found a wider diversity of bacteria in soil microaggregates of a no-till soil compared to tilled soil. Tillage changes the geospatial relationship of nematodes within the soil and most likely also affects the distribution of SCN antagonists (Gavassoni et al., 2001). With the mixed results in the literature we initiated this experiment to determine whether there was a tillage effect on SCN reproduction in our system and whether there were effects of long- (historical) and short-term (changed) tillage changes on SCN reproduction.

2. Materials and methods

2.1. Field site

This research was conducted from 2002 through 2005 as part of a long-term tillage experiment at West Tennessee Research and Education Center, Jackson, TN. The plot area (1 ha) had been in comparison of conventional tillage methods, disking (0.1 m deep), chisel plow (0.25 m deep), moldboard plowing (0.25 m deep), and conventional planting, to no-tillage planting in chemically killed wheat (*Triticum aestivum*) as a winter cover since 1979 (Table 1). The production crop was soybean (*Glycine max*). The soil is classified as a Lexington silt loam (fine-silty, mixed thermic ultic Hapludalf). Soil temperature data at 11 cm deep below bare soil

was available from the Jackson, TN official NOAA weather station (NOAA 40-4561-4) located 0.4 km from the field plot. Results from earlier research on this experimental site using the historical tillage treatments have been reported previously (Baird and Bernard, 1984; Bernard et al., 1996; Tyler and Overton, 1982; Tyler et al., 1983, 1987; Wrather et al., 1998).

2.2. Tillage regime

Historical tillage treatments were arranged as a Randomized Complete block design with 4 replications and 6 tillage treatments. The 6 tillage treatments had a nested treatment structure of till (yes, no) and till treatments within till. In 2002 at the beginning of the experiment, each plot was divided in half and additional paired treatments were established. With these additional paired treatment the experimental design is a Split plot with 6 main unit treatments as described above and subunit treatments as described as follows: Plots which had been historically tilled until 2002 were changed to one half tilled as previously and the other half no-tillage. Plots which had been historically no-tilled until 2002 were changed to one half no-tillage as previously and the other half was changed to disking and leveling (Table 1). Each subunit treatment replicate was 18 m long \times 6 m wide (108 m²) with four rows 1.5 m apart.

Egg population density was collected at planting and harvest which added an additional split to the design.

A bulk soil sample was collected representative of the entire plot area each fall and sent to the University of Tennessee Soil Test Laboratory (Nashville, TN) for standard soil analysis. Fertilizer was added to the entire plot based on the Laboratory results. Previous research from these plots measured bulk density of the tillage treatments (Tyler et al., 1994; Rhoton et al., 1993).

The plots were planted with Asgrow 4702 RR May 22, 2002 and harvested October 19, 2002. In 2003 Asgrow 5901 RR was planted June 5 and harvested October 22; in 2004 Asgrow 5501 RR was planted May 21 and harvested October 28; and in 2005 Asgrow 5905 was planted May 24 and harvested October 27. Based on company information, Asgrow AG 4702 is resistant to HG Type 0-(race 3) and HG Type 1.3-(race 14), AG 5901 and AG 5501 are resistant to HG Type 0-(race 3) and moderately resistant to HG Type 1.3-(race 14), and AG 5905 is resistant to HG Type 0-(race 3). The SCN population in the plot area was characterized as HG Type 1.2.5.7 (race 2) (Niblack et al., 2003). There are few commercial soybean cultivars with resistance to HG Type 1.2.5.7 (race 2) and none of these have glyphosate resistance. Current management suggestions are to rotate cultivars when sources of resistance cannot be obtained (Niblack, 2005). These cultivars were selected based on common usage in west Tennessee, herbicide resistance, and availability of these cultivars. Herbicide applications were standard for commercial production in west Tennessee. The grain was collected using a Massey Fergusson plot combine with computerized grain weight and moisture system. Yield data was standardized to 13% moisture.

2.3. Soil sampling

Soil was sampled for SCN at planting and at harvest each year of the study. Each plot was divided into five subplots on gridlines and soil samples were collected at the center of each of these subplots for a total of 20 soil samples per treatment. Six to eight soil cores (2.5 cm diam \times 20 cm deep) were collected at each subplot point, bulked by subplot in a plastic bag and transported to a cold room (4 °C) until processed.

2.4. Soil analysis

Soil samples for SCN were screened through 1/4 "mesh hardware cloth, thoroughly mixed and a 120 cm³ subsample

Table 1

Tillage treatments used to measure effects of long- and short-term tillage on soybean cyst nematode population density. Historical tillage was kept on half of the plot and the changed tillage was implemented on the other half in 2002.

Treatment designation	Historical tillage	Changed tillage
Disc (D)	D	D
Disc changed to no-tillage (D-NT)	D	D-NT
Chisel(C)	C	C
Chisel changed to no-tillage (C-NT)	C	C-NT
Moldboard (M)	M	M
Moldboard changed to no-tillage (M-NT)	M	M-NT
No-tillage in soybean stubble (NTS)	NTS	NTS
No-tillage changed to disc (NTS-D)	NTS	NTS-D
No-tillage with wheat cover since 1984 (NTW)	NTW	NTW
No-tillage in wheat changed to disc (NTW-D)	NTW	NTW-D
Long-term no-tillage with wheat cover since 1979 (LNT)	LNT	LNT
Long-term no-tillage changed to disc (LNT-D)	LNT	LNT-D

Table 2

Spatial model comparison values by year and by time of year of estimation of soybean cyst nematode population density.

Year	Bayesian information criterion (BIC)		
	Planting	Harvest	Model
2002	820.3	587.5	ExP
	820.3	584.9	ExPa
	825.0	588.4	Nothing
2003	669.5	748.9	ExP
	672.7	753.1	ExPa
	670.5	755.9	Nothing
2004	705.4	591.7	ExP
	698.8	593.7	ExPa
	728.3	615.5	Nothing
	572.7	548.3	ExP
2005	578.0	547.1	ExPa
	576.7	561.3	Nothing

ExP model = exponential, ExPa model = anisotropic exponential, nothing denotes no spatial variability. The smaller the BIC value the better the fit.

processed. SCN cysts were extracted from each soil sample using a semi-automatic elutriator (Byrd et al., 1976). The cysts were collected on the 250 μ m pore opening sieve, ground to release eggs with a motorized pestle (Faghihi and Ferris, 2000) and further processed following the procedures of Niblack et al. (1993). Eggs contained in an l-mL gridded Advanced Equine Products Nematode Slide (Issaquah, WA) were counted under a dissecting microscope using 12 \times magnification. Counts were adjusted for the volume of the total sample. SCN egg population density was transformed to log + 1 prior to analysis of variance. SCN reproductive rate was calculated as Pi (egg population density at planting)/Pf (egg population density at harvest) and expressed as a percent.

2.5. Statistical analysis

The nematode data were subjected to analysis of variance using the Mixed Model procedure of SAS (SAS Institute, 2002) for the split plot design previously described. Egg population density was log transformed prior to analysis. The residual error measurements for egg population density data were checked for spatial variability. Several models were evaluated to describe the spatial variability and analysis was performed using the best model. Spatial correlation using an exponential model, anisotropic exponential model, and a model assuming no spatial correlation are compared in Table 2. Model comparisons were based on the Bayesian information criteria (BIC) to guard against overfitting the model, i.e. incorporating a spatial component to the analysis when

Table 3

Composite average of planting, harvest population densities of soybean cyst nematode and soybean yield in a west Tennessee field from 2002 through 2005.

Year	Parameter	Range ^a	Mean	Std. deviation
2002	Planting	0–19,200	1686	1405.1
	Harvest	0–2,600	206	198.5
	Yield ^b	806–1,814	1411	3.8
2003	Planting	0–760	56	62.9
	Harvest	0–6,040	459	512.8
	Yield	2,217–3,360	2889	3.0
2004	Planting	0–1,200	352	320.9
	Harvest	0–16,928	4152	3284.8
	Yield	2,150–4,300	3158	7.4
2005	Planting	0–17,320	1677	1419.4
	Harvest	0–12,320	1237	783.2
	Yield	1,814–3,964	3091	6.5

^a 0 = below detection threshold, eggs expressed as number per 120 cm³ of soil.

^b Yield expressed as kg/ha soybean cultivars were Asgrow 4702 RR (2002), Asgrow 5901 RR (2003), Asgrow 5501 RR (2004) and Asgrow 5905 (2005).

Table 4

Comparison of tillage treatments (changed and historical) on soybean cyst nematode population density using geometric means from 2002 through 2005 in a field in west Tennessee.

Treatment ^a	2002	2003	2004	2005
D	7.28	2.70	9.61	15.51
C	5.21	2.49	7.14	15.22
M	7.91	2.52	5.77	8.50
NTS	6.36	4.49	19.37	17.29
NTW	9.12	5.26	15.31	21.98
LNT	4.63	4.01	15.45	19.39
L.S.R. ^b	2.2	1.58	1.86	1.5
Till average	6.8	2.6	7.5	13.1
No-till average	6.7	4.6	16.7	19.6
L.S.R. ^b	2.45	1.91	2.41	1.78

^a D: disc, C: chisel, M: Moldboard, NTS: no-tillage in stubble, NTW: no-tillage in wheat, LNT: long-term no-tillage.

^b L.S.R. (least significant ratio) values ($p < 0.05$) are the equivalent of the L.S.D. for data that have been log transformed.

it is not necessary (Schwarz, 1978). BIC is a statistical criterion for model selection using only an in-sample estimate of the model. It assumes that the data distribution is exponential and favors simple over highly complex models.

Composite average of plant and harvest SCN population densities and yield data are presented in Table 3. Egg population density at planting and harvest was transformed using a log transformation. The log-normal distribution is a distribution

Table 5

Comparison of long-term effects (historical) of tillage treatments on soybean cyst nematode population density expressed as geometric mean and reproductive factor (Pf/Pi) for each year of the study.

Treatments ^a	2002		2003		2004		2005	
	Mean	Pf/Pi ^b	Mean	Pf/Pi	Mean	Pf/Pi	Mean	Pf/Pi
D	7.65	47	3.46	83	12.37	116	23.22	83
C	4.45	48	3.10	24	10.70	62	21.01	90
M	7.35	81	2.56	79	8.27	31	11.33	151
NTS	3.66	69	2.72	326	17.03	79	14.44	110
NTW	8.71	54	3.93	84	12.06	132	22.76	15
LNT	4.43	39	3.85	94	13.74	61	16.86	66
L.S.R. ^c	2.45		1.91		2.41		1.78	
Till average	6.5	58.7	3.1	62	10.5	69.7	18.5	108
No-till average	5.6	54	3.5	168	14.3	90.7	18.03	63.7

^a D: disc, C: chisel, M: Moldboard, NTS: no-tillage in stubble, NTW: no-tillage in wheat, LNT: long-term no-tillage.

^b Pf/Pi calculated as (egg population density at harvest/egg population density at planting) \times 100. A value of 100 indicates no change in nematode population density.

^c L.S.R. (least significant ratio) values ($p < 0.05$) are the equivalent of the L.S.D. for data that have been log transformed.

Table 6

Comparison of short-term (changed) effects of tillage treatments on soybean cyst nematode population density expressed as geometric mean and reproductive factor (Pf/Pi) for each year of the study.

Treatments ^a	2002		2003		2004		2005	
	Mean	Pf/Pi ^b	Mean	Pf/Pi	Mean	Pf/Pi	Mean	Pf/Pi
D-NT	6.93	125	2.11	44	7.46	95	10.36	94
C-NT	6.09	43	2.00	145	4.77	42	11.02	134
M-NT	8.50	44	2.47	161	4.02	184	6.38	45
NTS-D	11.06	105	7.41	68	22.03	191	20.70	144
NTW-D	9.56	140	7.05	93	19.44	170	21.22	125
LNT-D	4.83	168	4.18	122	17.97	177	22.31	67
L.S.R. ^c	2.32		1.91		2.41		1.78	
Till average	7.2	70.7	2.2	116.7	5.4	107	9.3	91
No-till average	8.5	137.7	6.2	94	19.8	179	21.4	112

^a D-NT: disc changed to no-tillage, C-NT: chisel changed to no-tillage, M-NT: Moldboard changed to no-tillage, NTS-C: no-tillage in stubble changed to disc, NTW-C: no-tillage in wheat changed to disc, LNT-C: long-term no-tillage changed to disc.

^b Pf/Pi calculated as (egg population density at harvest/egg population density at planting) \times 100. A value of 100 indicates no change in nematode population density.

^c L.S.R. (least significant ratio) values ($p < 0.05$) are the equivalent of the L.S.D. for data that have been log transformed.

which is normal for the logarithm transformed values. Since the log transformed values were analyzed, means based on these log transformed values were back transformed to the original scale which by definition is referred to as geometric means as shown in Tables 4–6. Least significant ratios (L.S.R.) ($p < 0.05$) were calculated by taking antilog of least significant differences (L.S.D.) derived from statistical analysis of log transformed data. A difference on a log scale becomes a ratio when back transformed, therefore the L.S.D. is defined as a ratio (L.S.R.) in order to present data using the original scale. If the ratio between two values is greater than the L.S.R. then the difference between them is unlikely to have occurred by chance. Yield data were subjected to analysis of variance according the GLM procedures of SAS (SAS Institute, 2002).

3. Results and discussion

The effects of tillage on SCN were measured by population density for each treatment over time and by reproductive factor by treatment over time. A summary of the range of SCN egg population density found in the plot site is presented in Table 3. Based on the summary statistics for planting and harvest egg counts in this table, it is obvious that a log transformation of the data is needed for analysis. Table 2 contains the Bayesian information criteria (BIC). Low values are an indication of better fit and in every comparison the BIC indicates that there is a spatial pattern to distribution of SCN in the field. No significant differences were found in sample collection date (planting and harvest) within a year therefore, sampling date egg counts were not analyzed separately.

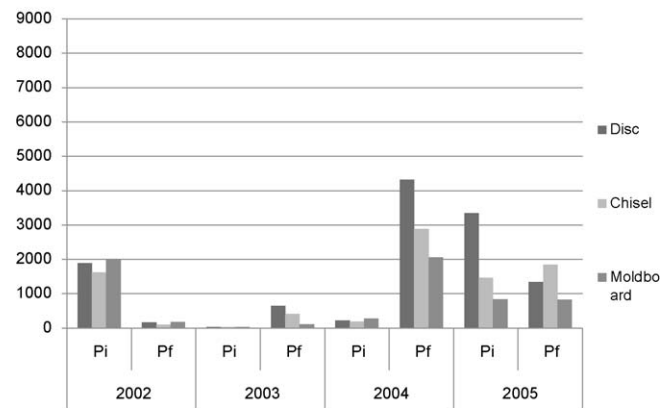
3.1. Soybean cyst nematode population density between till and no-till

The data presented in Table 4 combines the egg population density by treatment regardless of whether the treatment was long-term (historical) or short-term (changed). There was a significant difference in egg population density between historical tillage treatments (tilled and no-tillage) with the exception of 2002 (Table 4). The data presented in Tables 5 and 6 separates out the data by duration of the treatment, i.e. historical or changed. Table 5 data are comparisons of egg population density of treatments which were classified as long-term and Table 6 contains egg population data from treatments which are classified as short-term. No differences were found in SCN population density between tilled and no-tillage treatments (Table 5). However, where the treatment

changes were recent there were significant differences between tilled and no-tillage treatments. The egg population density in 2003 (L.S.R. 1.9), 2004 (L.S.R. 2.4) and 2005 (L.S.R. 1.8) was significantly higher in no-tillage treatments changed to disc treatments than tilled treatments changed to no-till (Table 6). SCN reproductive rate in the short-term (changed) treatments was 1.5 times that of the long-term treatments from 2002 through 2005.

SCN population density was not different among the tilled treatments nor the no-tillage treatments in 2002, 2003 and 2004.

**SCN Population Density (Eggs/120 cc soil)-
Tilled Unchanged**



**SCN Population Density (Eggs/120 cc soil)-
Tilled Changed to No-tillage**

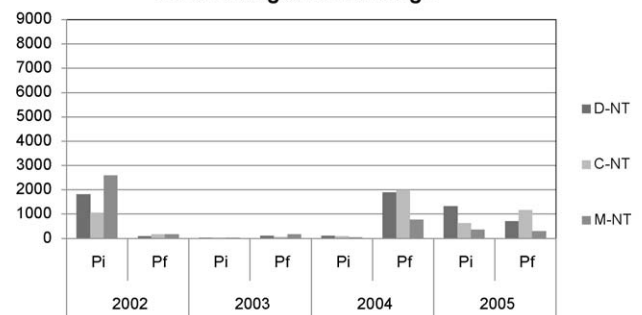


Fig. 1. Long- (unchanged) and short- (changed) term effects of tillage on SCN population density expressed as egg counts.

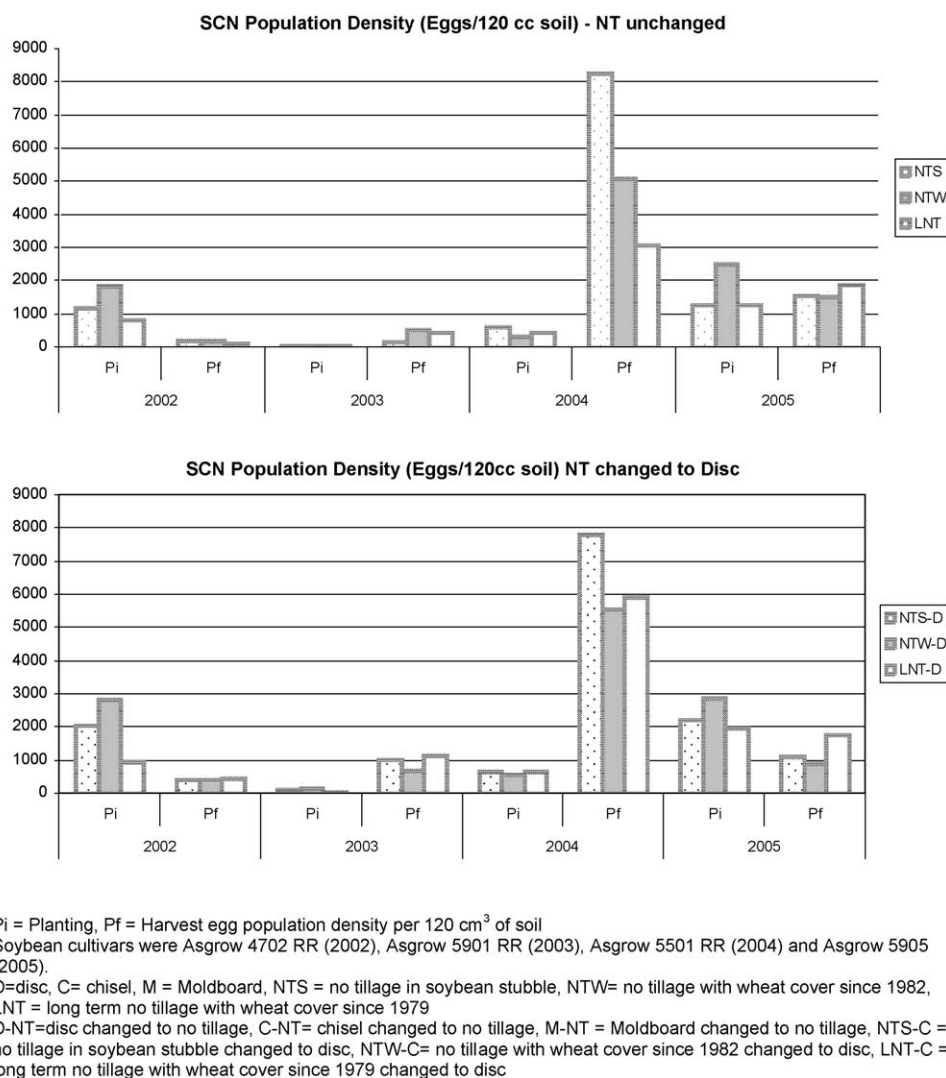


Fig. 2. Long-term (unchanged) and short-term (changed) effects of no-tillage on SCN population density expressed as egg counts.

Although there was a statistically significant difference in population density between chisel and moldboard treatments it is not clear whether this is biologically significant (Table 4). No significant differences were found among the different tilled or no-tillage treatments when historical treatments were compared (Table 5). Short-term (changed) effects of tillage on SCN egg population density are presented in Table 6. When within tillage treatments were compared in the treatments which had tillage changes there was a significant lower SCN population density in the LNT-D than the NTS-D treatment (L.S.R. 2.3) but no differences in the other no-tillage treatments or in the tilled treatments which went into no-tillage in 2002.

Data, presented as raw egg population density for historical and changed effects of tillage on SCN population density, are presented in Fig. 1 for historical tilled treatment comparisons and in Fig. 2 for historical no-tillage treatment comparisons. The lack of significant differences in the population density in the long-term treatments suggests that the populations reach equilibrium and the population density level is then influenced by the interaction of the nematode with the soybean cultivar planted. Data from the short-term treatments suggests that our sites would require more than three years after soil disturbance to reach equilibrium. It is plausible that different geographic sites would reach equilibrium at different

rates depending on the biotic and abiotic interactions at each site.

3.2. Environmental differences in years

Data were analyzed by year and not combined over the entire length of the experiment due to environmental influences on nematode reproduction and use of different soybean cultivars each year. Soil temperatures for the years 2002 through 2005 collected at 11 cm below bare soil were similar to the 20 year average (1986–2006). Rainfall accumulation during the growing season through August was much lower in 2002 than the other years of the study which explains much lower yield that year.

3.3. Yield

No significant yield differences in tillage treatments were found in any year of the study. Yields in 2002 were much lower than in the other years of the study due to drought. Comparison of yields in historically tilled treatments is presented in Fig. 3. Comparison of yields in historically no-tillage plots is presented in Fig. 4. Our data is consistent with what Denton and Tyler (2002) found previously in Tennessee for the effect of tillage on yield.

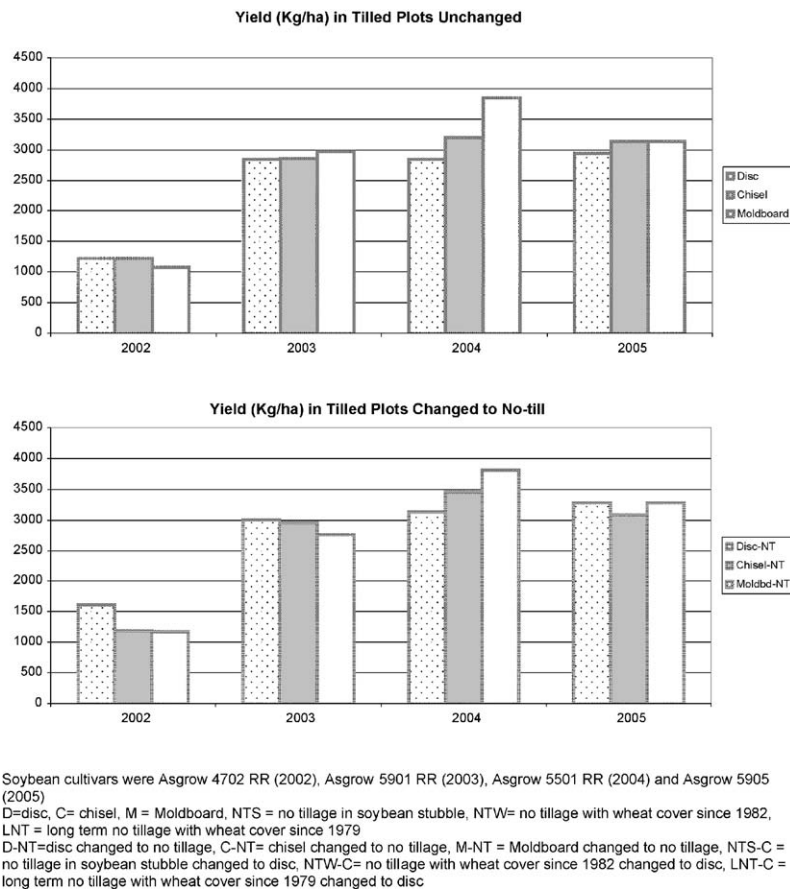


Fig. 3. Comparison of yield in long-term (unchanged) and short-term (changed) tillage treatments from 2002 through 2005.

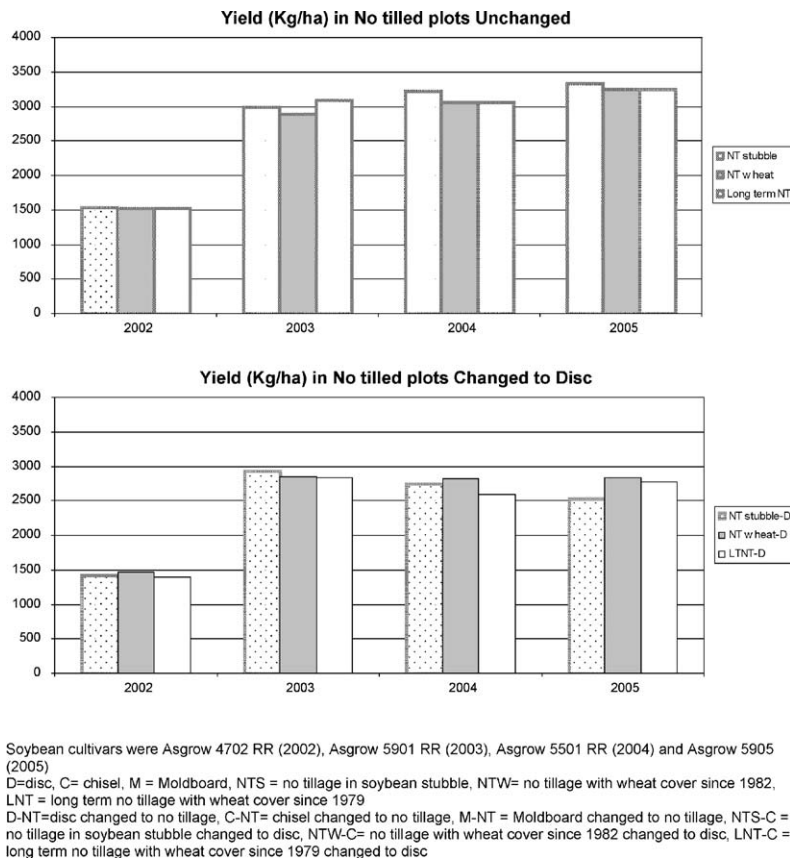


Fig. 4. Comparison of yield in long-term (unchanged) and short-term (changed) tillage treatments from 2002 through 2005.

Differences in the effect of tillage on SCN population density have been previously reported and have not been consistent. Conflicting results from studies such as the regional study in the north central states (Atibalentja et al., 2001), where tillage data were compared from different historical land usage could be explained by our results where we have shown that the time between treatment initiation and measurement can affect the results. Workneh et al. (1999) suggest that the relationship between tillage and SCN population density is confounded by soil type. Young (1987) on the other hand conducted an ingenious experiment and found that any disturbance of the soil would lead to an increase in soybean cyst nematode reproduction. This finding confirms our observed higher SCN population density in plots converted from no-tillage to disc tilled but the mechanism of this phenomenon has not been elucidated. One could assume all the mechanical processes that occur with tillage such as increased oxygenation, redistribution of natural predators and mixing of organic matter may play a role in the increased SCN reproduction either singly or in combination.

4. Conclusions

Greater differences in SCN population density by treatment were observed when data was analyzed by length of time since initiation of treatment was considered. Differences in tillage treatments were masked when treatments included long- as well as short-term treatments. SCN reproductive rate in the short-term (changed) treatments was 1.5 times that of the long-term treatments from 2002 through 2005. In 2005 the reproductive rates were similar indicating that more than three years were needed at our location for the SCN population density to reach equilibrium in the tillage treatments. No differences were found in population density between tillage treatments in historical treatments. SCN reproductive rate was higher in no-till plots which were tilled than in tilled plots which went into no-tillage in 2002, 2004, and 2005. Our study supports Tyler's earlier hypothesis that the effect of tillage on SCN population density is related to the timing between the tillage practice initiation and the measurement of the effect on SCN. More research is needed to elucidate the mechanism of the role of tillage on SCN reproduction to better understand biotic and abiotic regulators of SCN population density.

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